Fifty Years of Exploration Science with the Deep Space Network

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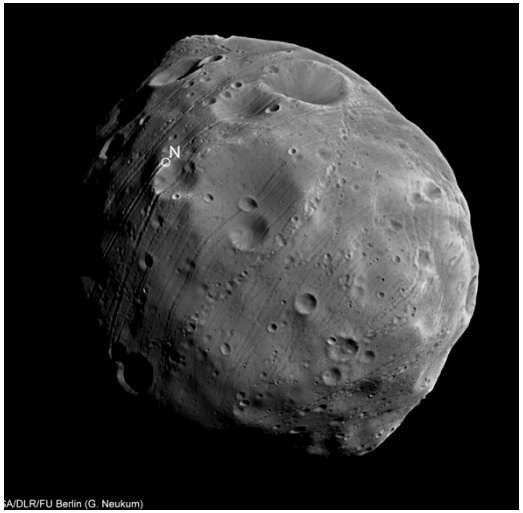
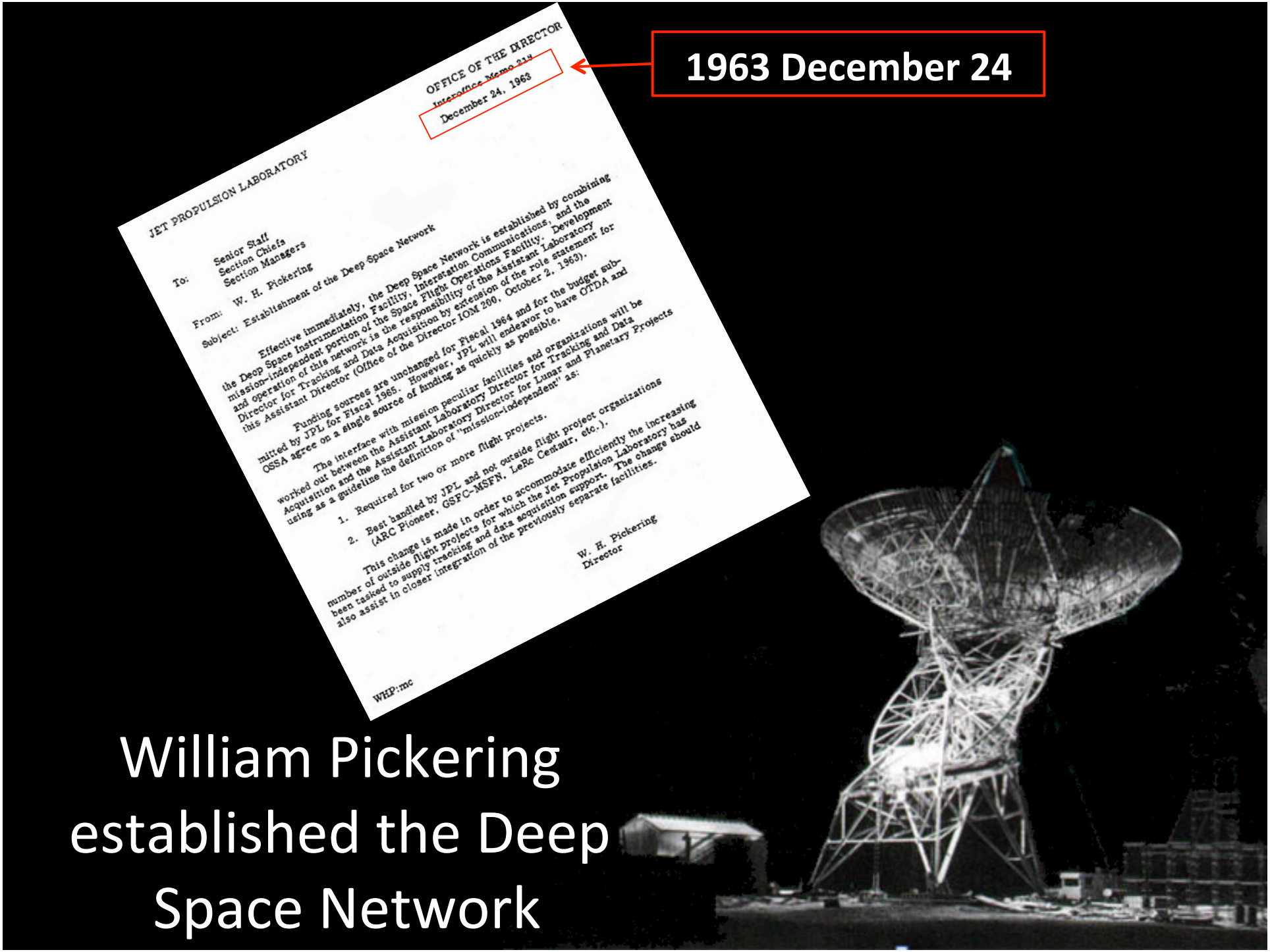
Deep Space Network and Solar System Exploration

Deep Space Network has been, is, and will be an integral component of human and robotic exploration of (inner) solar system



Deep Space Network

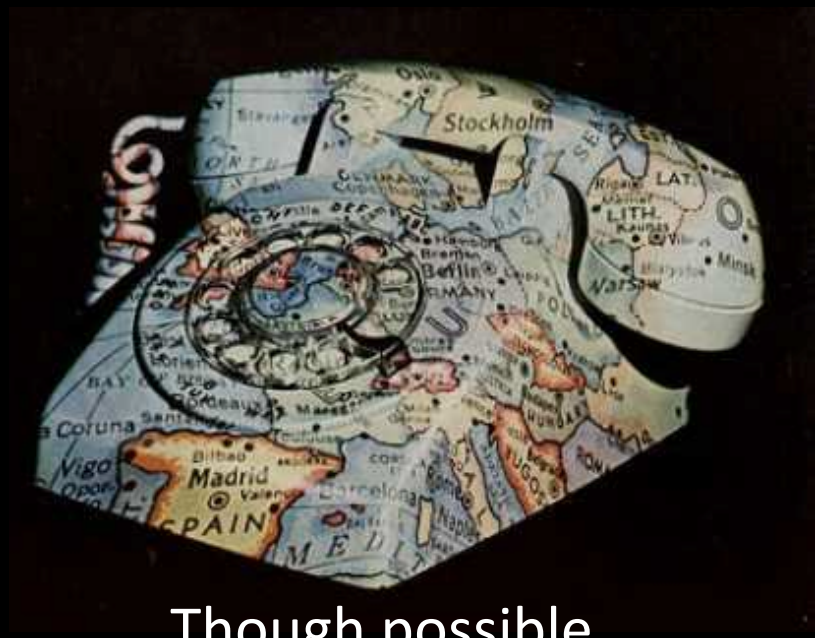
- Three major tracking sites around the globe, with 16 large antennas, provide continuous communication and navigation support for the world's deep space missions
- Currently services [illegible] foreign agencies
- Spigot for science [illegible] nts exploring the solar system
- $2B infrastructure [illegible] t of 10's of $B of [illegible] r the last few



William Pickering established the Deep Space Network

1963

Moscow-Washington “Hot Line” not a red telephone, but a teletype!

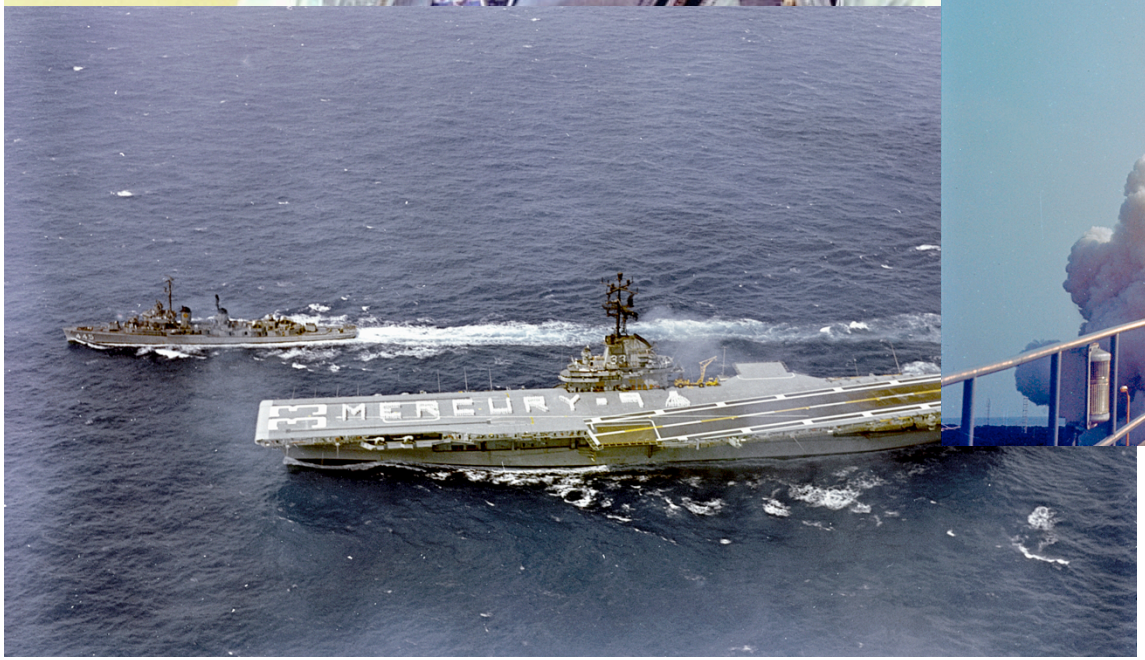


Though possible, intercontinental phone service was still “iffy.”

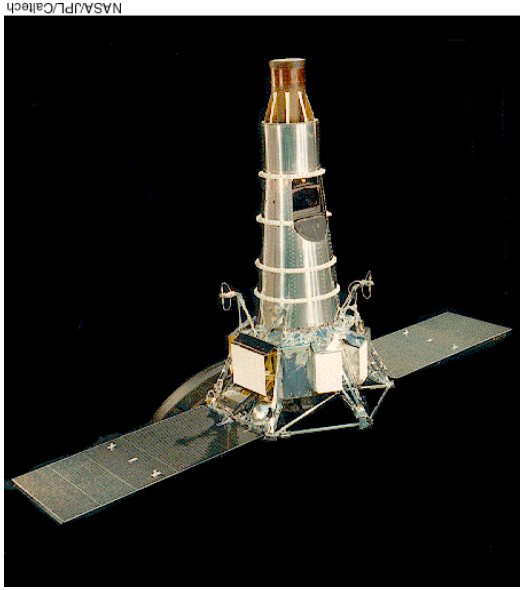
1963

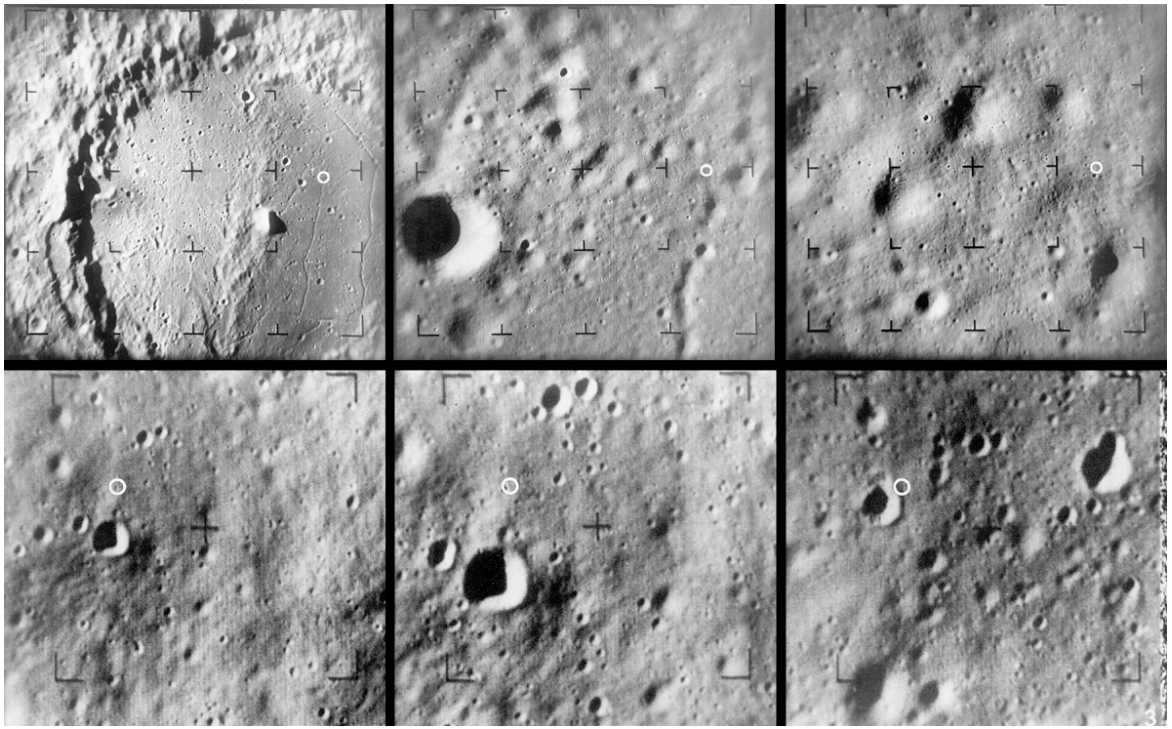

1963
WGBH-TV

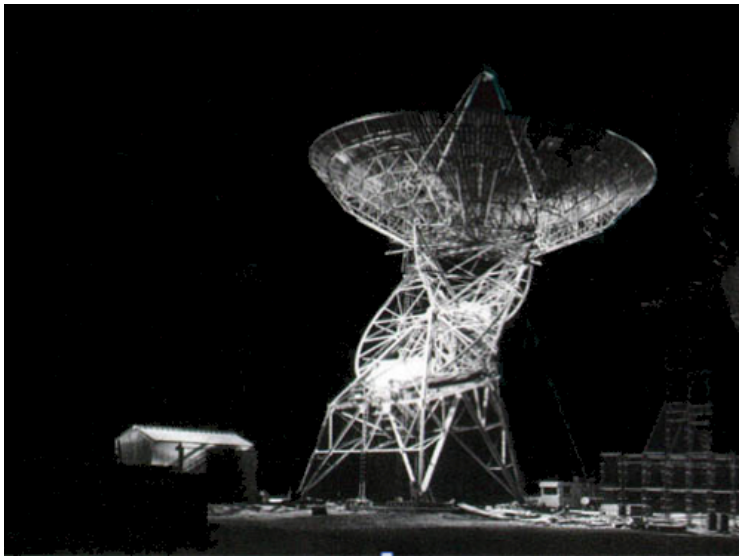
1963



Ranger and the Moon







Ranger program provides first, close-up images of surface of another world (1964--1965)

1964 July 31 – Ranger 7

Moon Landing

In 1969 Neil Armstrong became first human to step onto the Moon.

Samples returned by *Apollo* astronauts spur giant impact model for the origin of the Moon.

Apollo astronauts emplace Far Ultraviolet Camera/Spectrograph, first lunar-based telescope

The DSN provided communications and tracking for all* Apollo *missions

The DSN relayed the video of Armstrong's first steps on the lunar surface

Deep Space Network and Solar System Exploration

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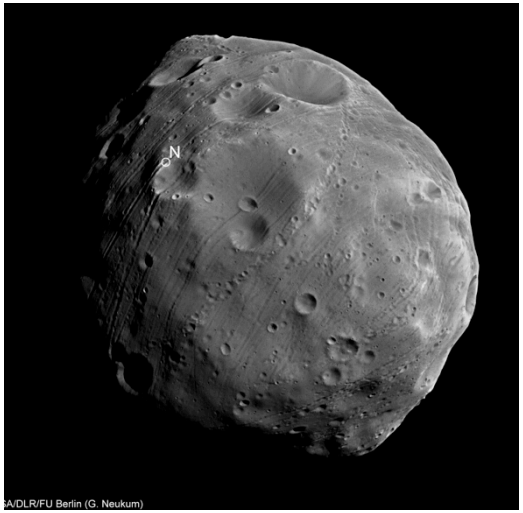
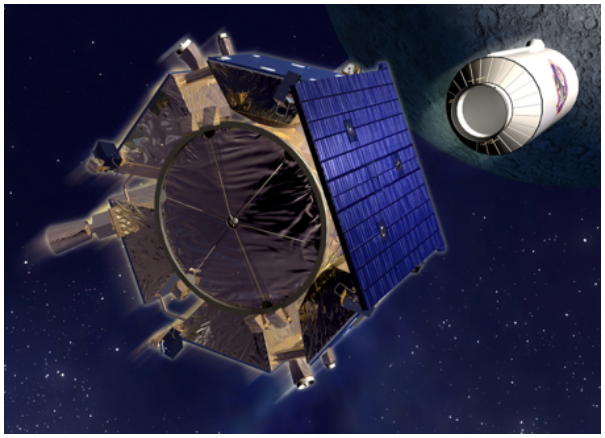


Water on the Moon

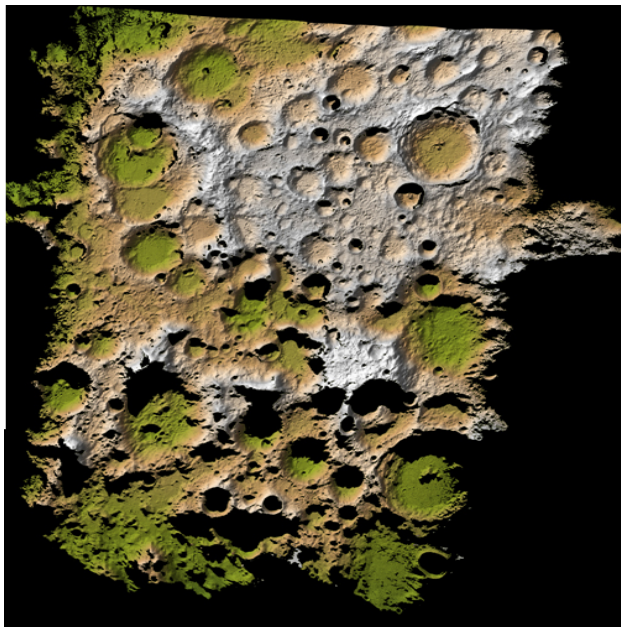


In 2009, LCROSS was intentionally crashed into the Moon.

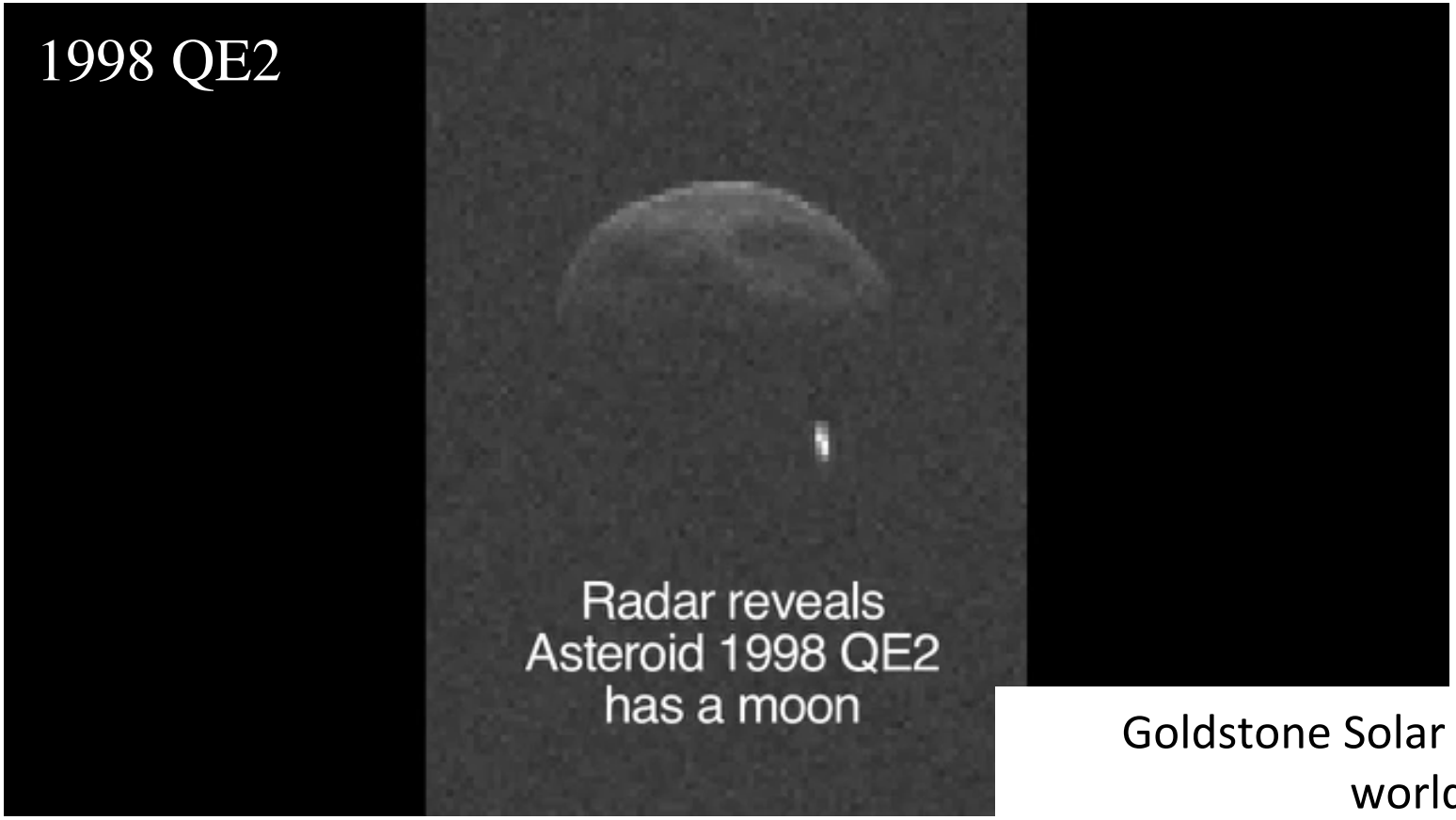
Water was observed in its plume.

First evidence of water on the Moon provided by radar observations – from Arecibo and the DSN.

The DSN continues to study these regions on the Moon in support of future human exploration.



Solar System Radar

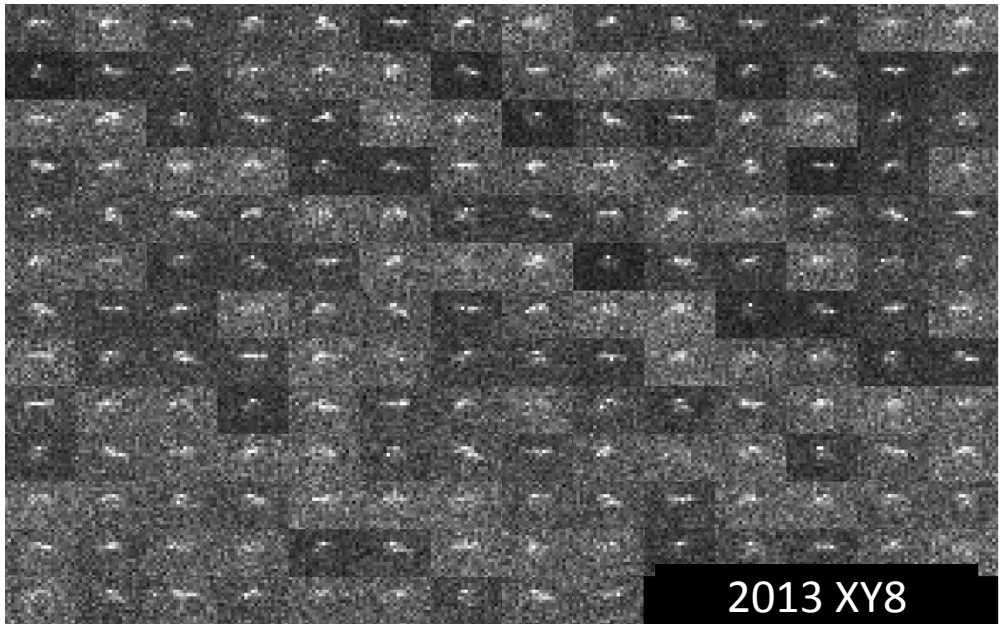


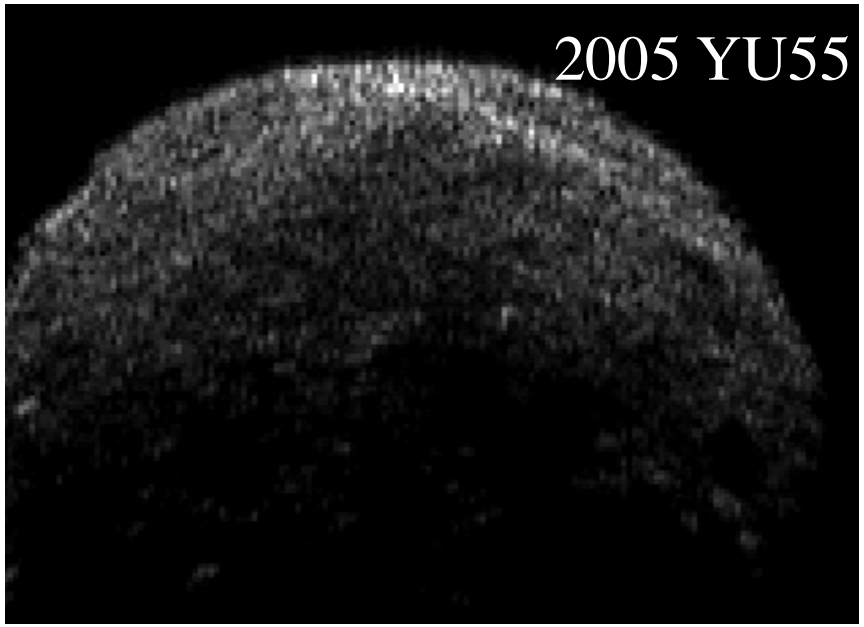
"Radar Reconnaissance of Near-Earth Asteroids"
L. Benner (July 21)

Goldstone Solar System Radar is world-leading facility

- Precise orbital determination
- Rotation periods
- Surface features, with encounter-quality 3.7 m resolution imaging
- Mass, shape, and density

Solar System Radar

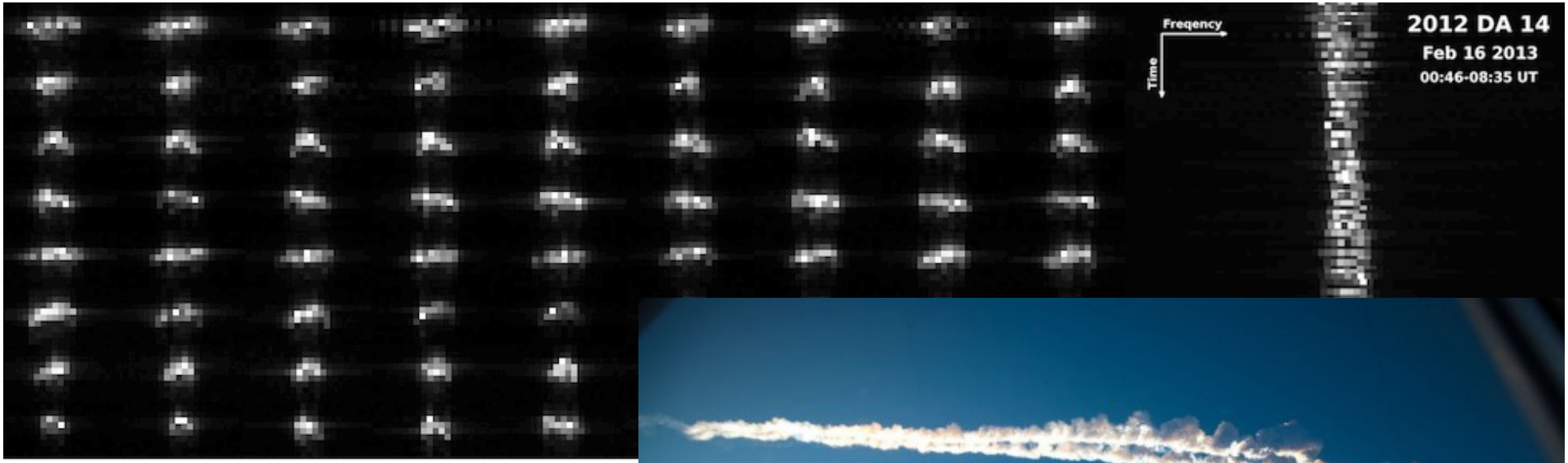




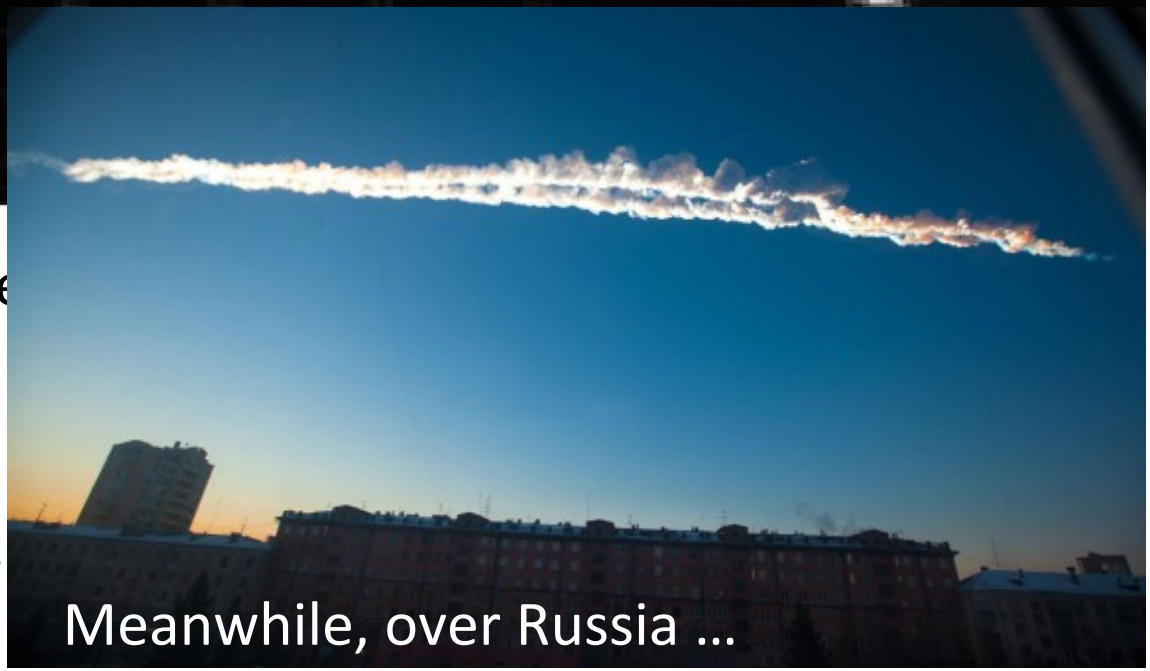
- **Routinely observing asteroids < 200 m diameter**
  - **... approaching 10 m class objects**
- **Detecting surface features**
- **Rapid turn-around observations**
  - **< 8 hr in one case**
- **Monostatic GSSR short round-trip observations**
  - **Detection not possible in one case without it!**
  - **Potential new capability**

Solar System Radar

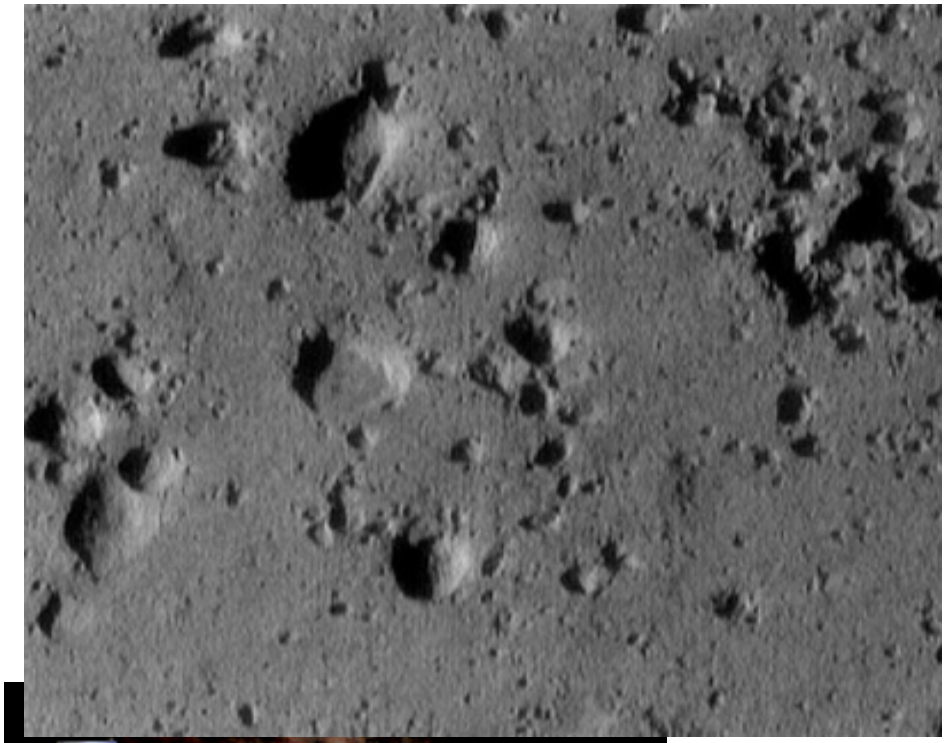
Goldstone Radar Images of 2012 DA14
2013 Feb 16

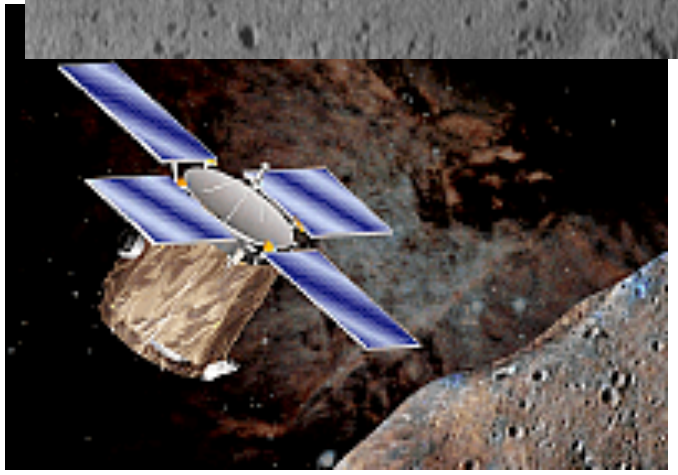


- Elongated obje
- P > 8 h
- Earth torques
  the spin state.



Missions to Asteroids





NEAR-Shoemaker provided information about 433 Eros

- **Topography**
- **Surface mineralogy**
- **Composition**
- **Gravitational field and interior**

… all delivered by the DSN

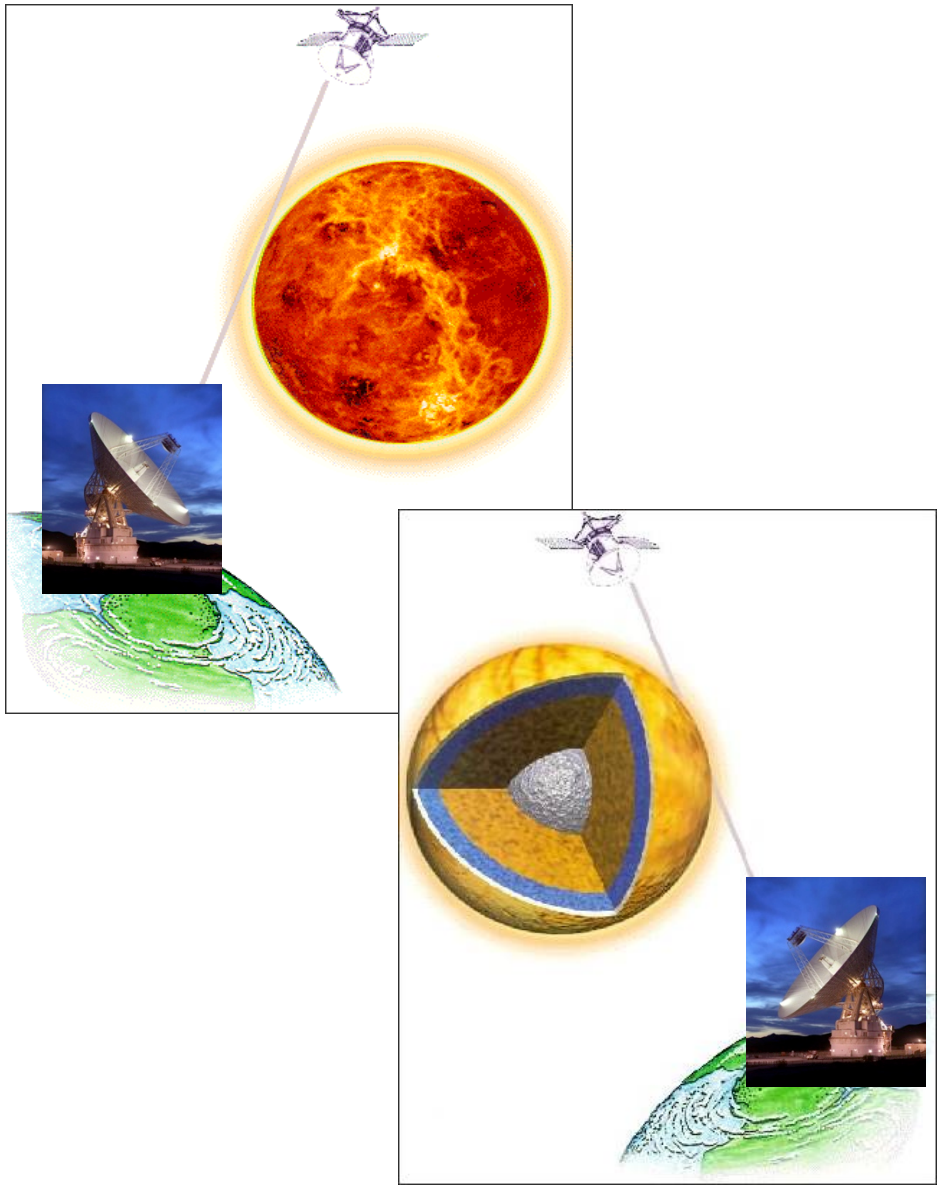
Mass	$(6.687 \pm 0.003) \times 10^{18}$ g
Bulk Density	2.67 ± 0.03 g/cm^3
Spherical harmonics	C_{10} to S_{44}

Radio Science

Apparent even with early missions that occultations by planetary atmospheres would affect the quality of radio communications

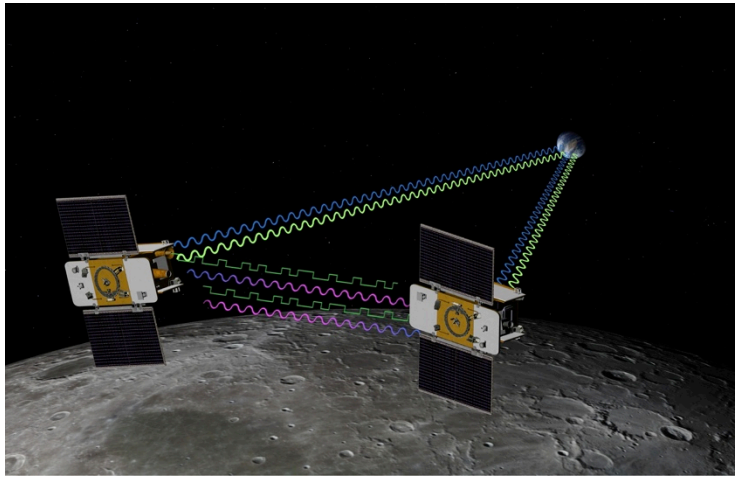
- **Mio dio! Tragedy!**
- **Or … one person's annoyance is another's data --- Study the atmospheric properties!**
- **Can also study planetary interior!**

➢ **Turn the DSN+spacecraft into one giant science instrument**

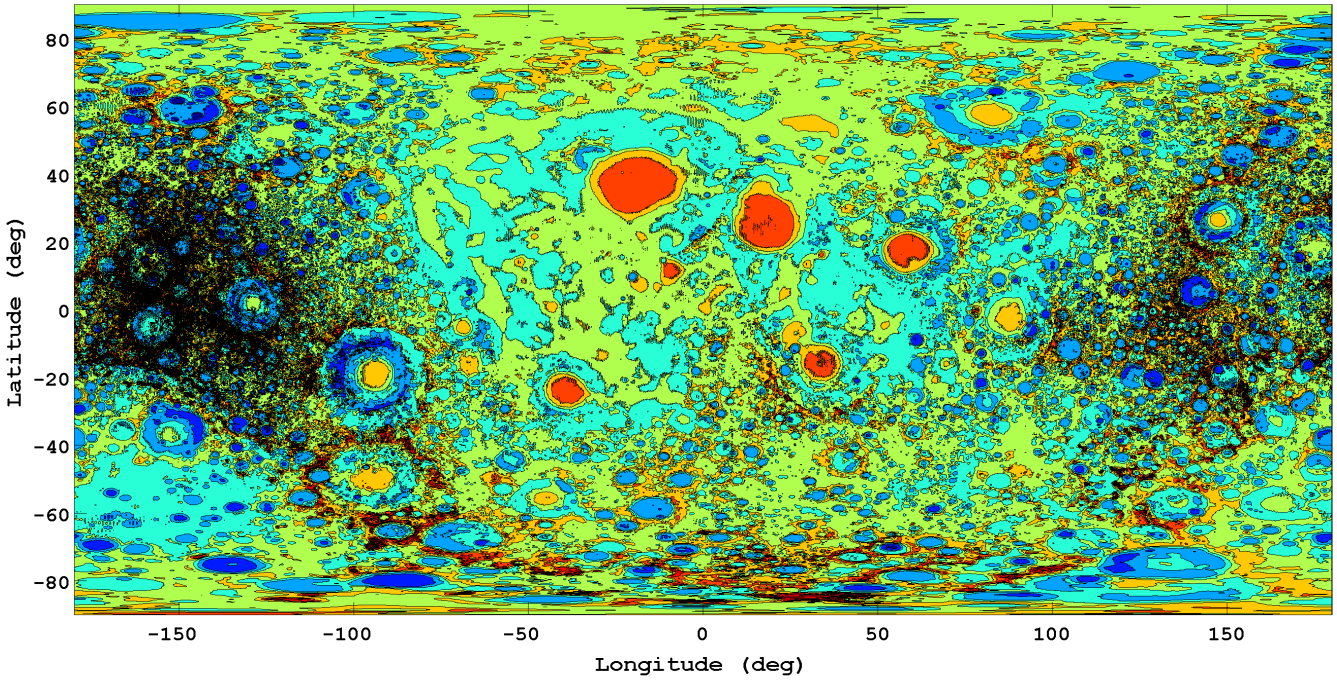


GRAIL Revealing Lunar Interior

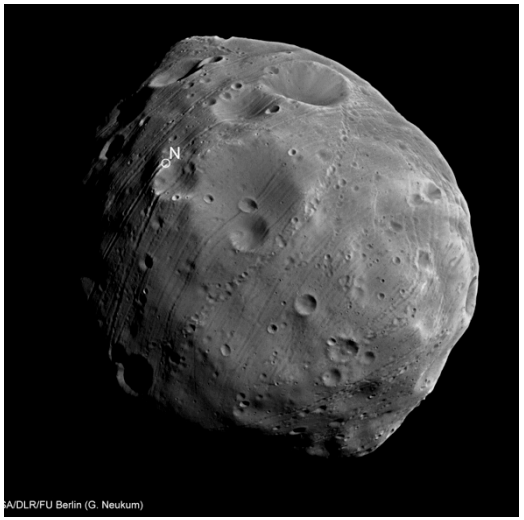
- GRAIL mission made precise measurements of separation between two spacecraft orbiting the Moon
- Changes in separation due to acceleration of one of the spacecraft
- Changes in acceleration result from changes in mass along spacecraft trajectory …



Extending radio science techniques developed at the DSN



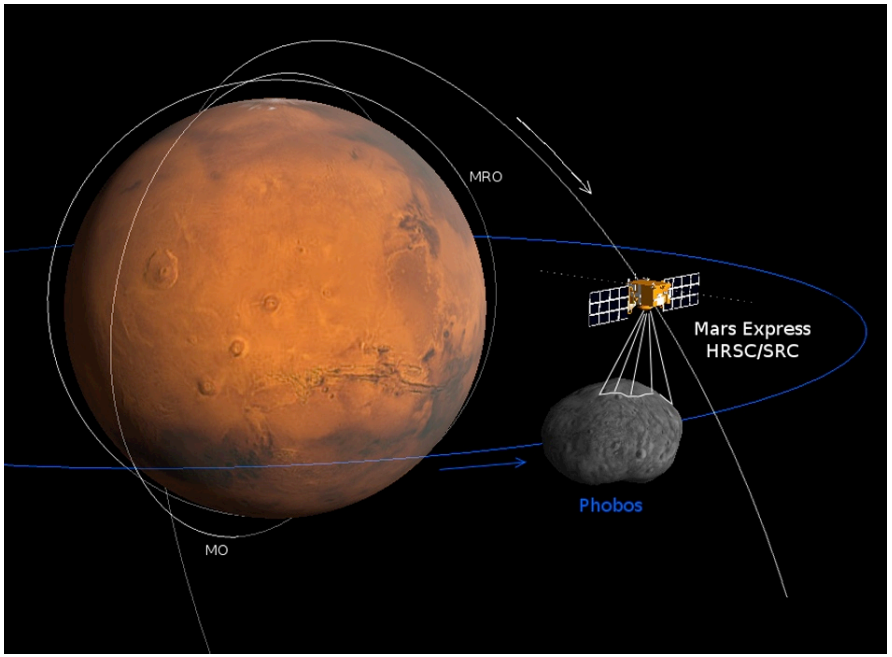
Radio Science
Phobos

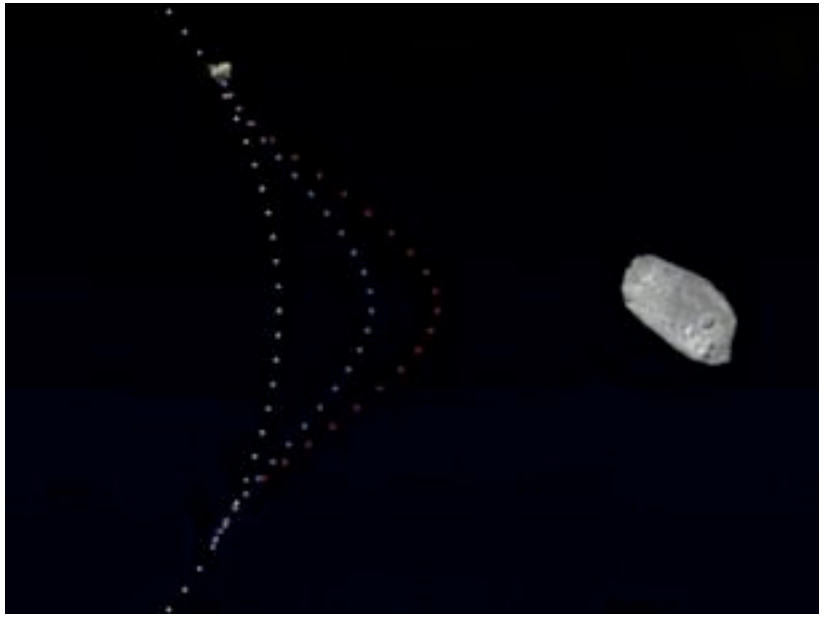


DSN radio science measurements with ESA Mars Express fly-by

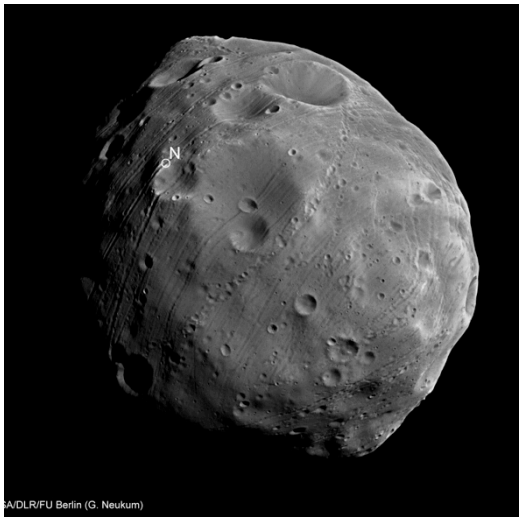
- **Determine mass and bulk density**

  $\rho_{bulk} = 1862 \pm 20$ kg/m^3





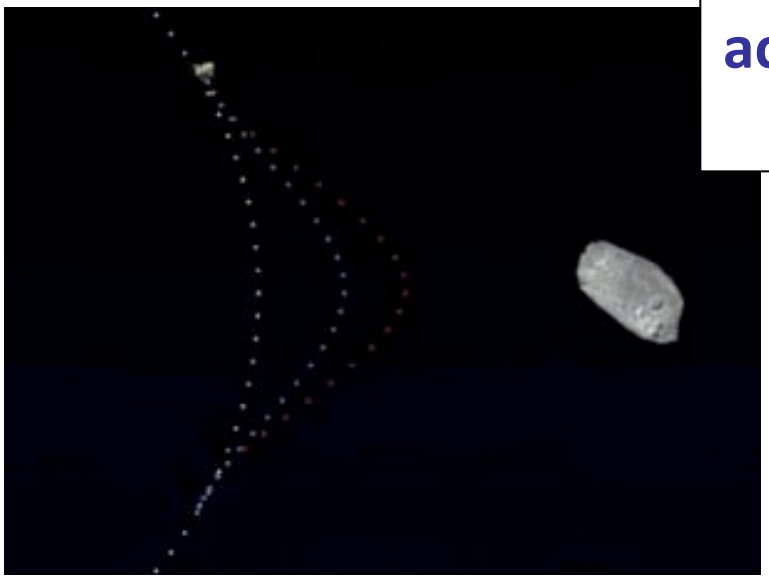
Radio Science
Origin of Phobos

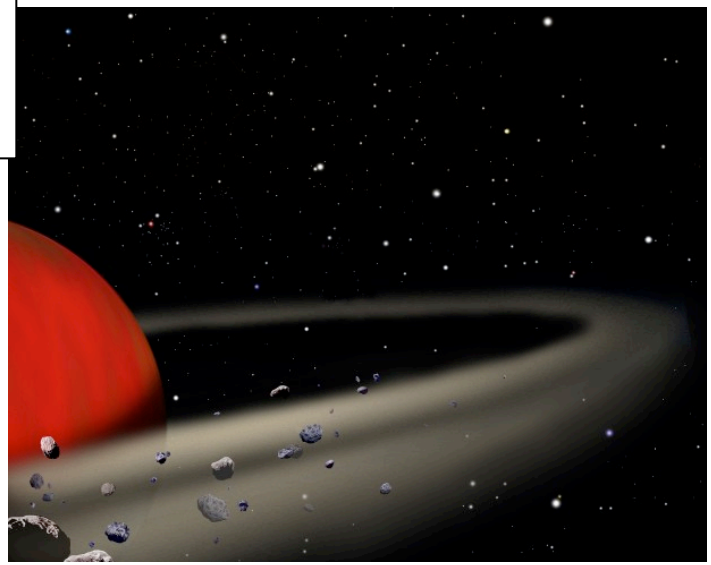


DSN radio science measurements with ESA Mars Express fly-by

- **Bulk density (considerably) lower than "solid" bodies**
- **Has lots of "gaps" inside (a.k.a. "high porosity")**

Phobos re-accreted in place! (?)





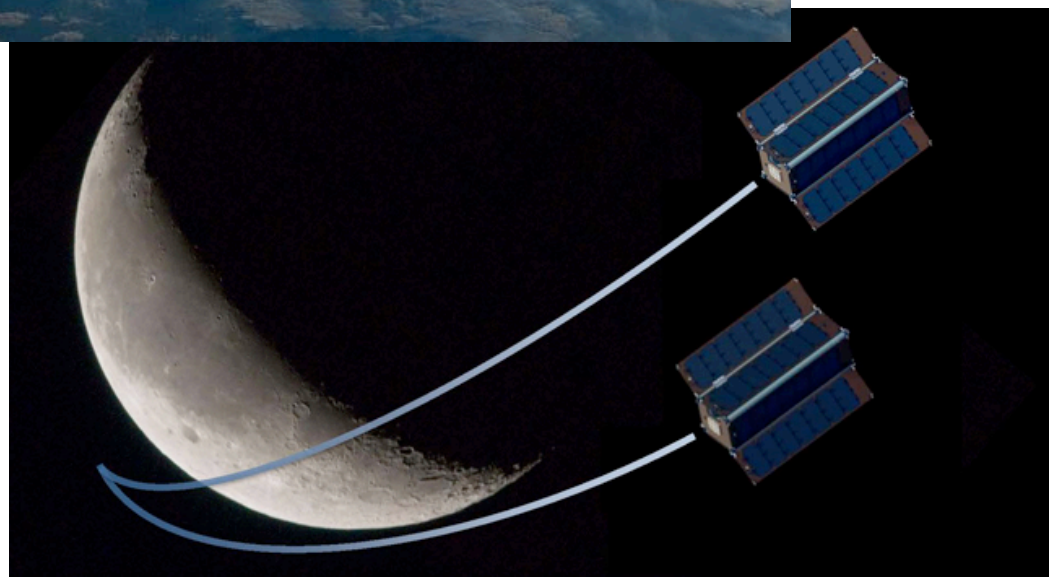
Next 50 Years?

Next 50 Years?

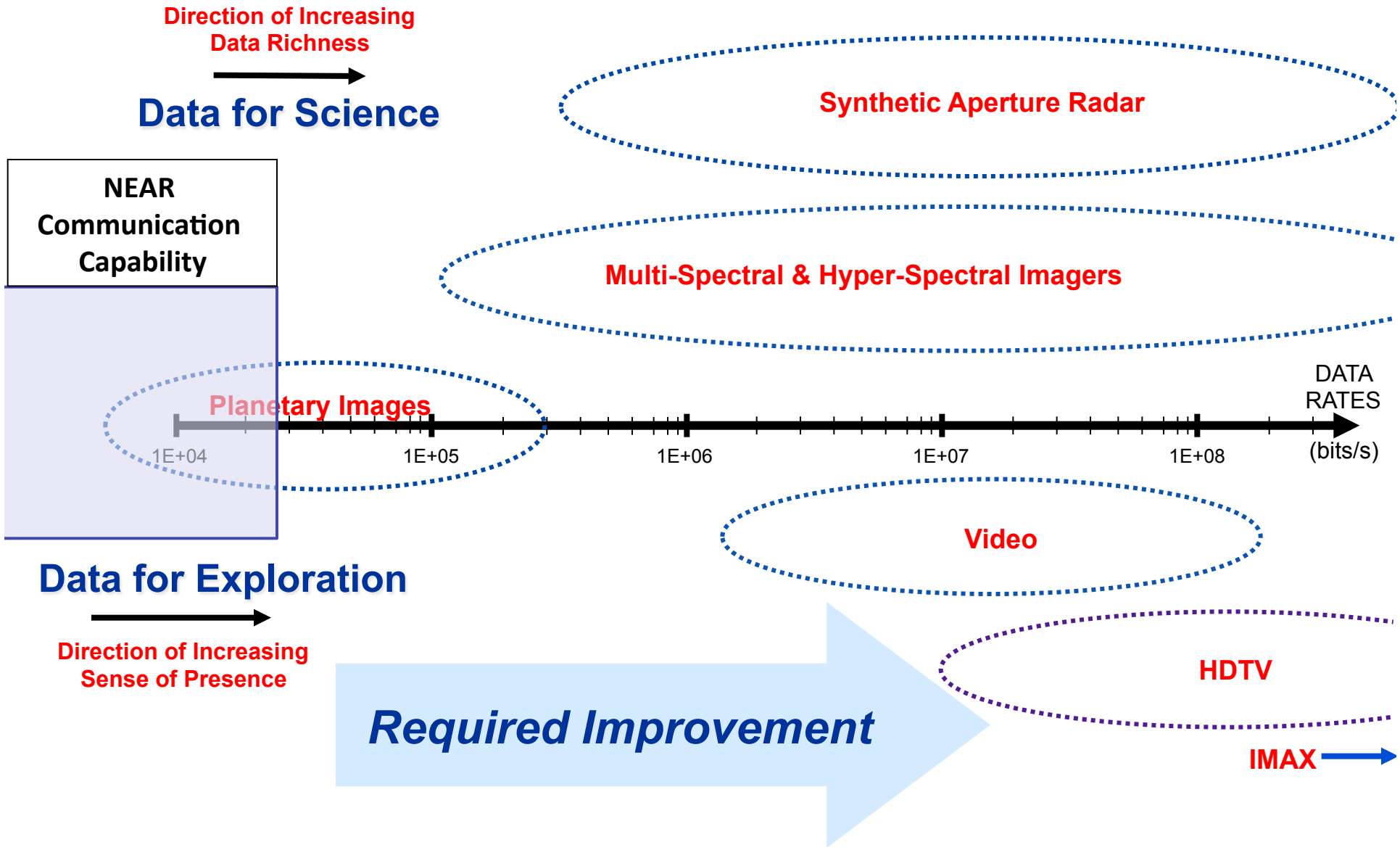
- Optical communications
- Interplanetary Internet
- Complete catalog of NEOs
- Detection of gravitational waves
- Deep space industry
- Humans on Mars
- Extraterrestrial life

Deep Space SmallSat Constellations

- Imagine fleets of spacecraft at other bodies …
- May be possible with “smallsats”
- Lunar Flashlight, NEO Scout attached to E-M 1
- Requires whole new way to operate the DSN …



Remote Sensing at Other Planets as at Earth



Beyond the Moon Landing

In 1969 Neil Armstrong became first human to step onto the Moon.

The DSN supported all the Apollo missions, providing communications and tracking.

Where next?

Beyond the Moon Landing

Humans in Deep Space

Deep Space Industry?

Moving humans and industry into deep space will require deep space communications. DSN baselined for cis-lunar space for E-M 1, E-M 2, ….

Laser Communication

- Lasers have the potential to offer much higher communication bandwidths, i.e., more science data!
  - Like fiber optics, without the fiber
- Already demonstrated …
  - In cis-lunar space
  - Not yet in deep space …
  - Discovery AO

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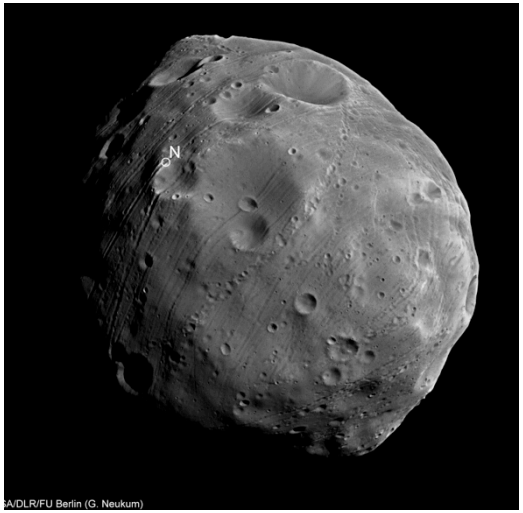
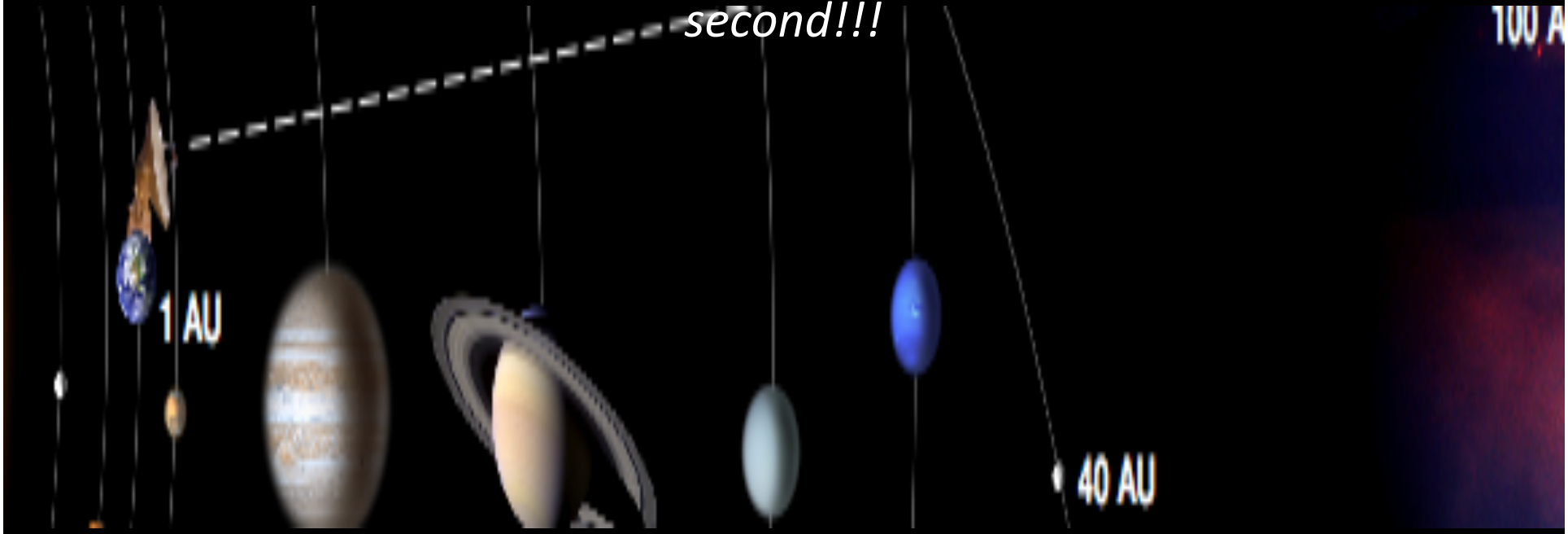


BACKUP

The Ultimate Long Distance Carrier

The power received by 70 m DSN antenna from Voyager is so small that if it were to be accumulated for 10 trillion years, it could power a refrigerator light bulb for one second!!!



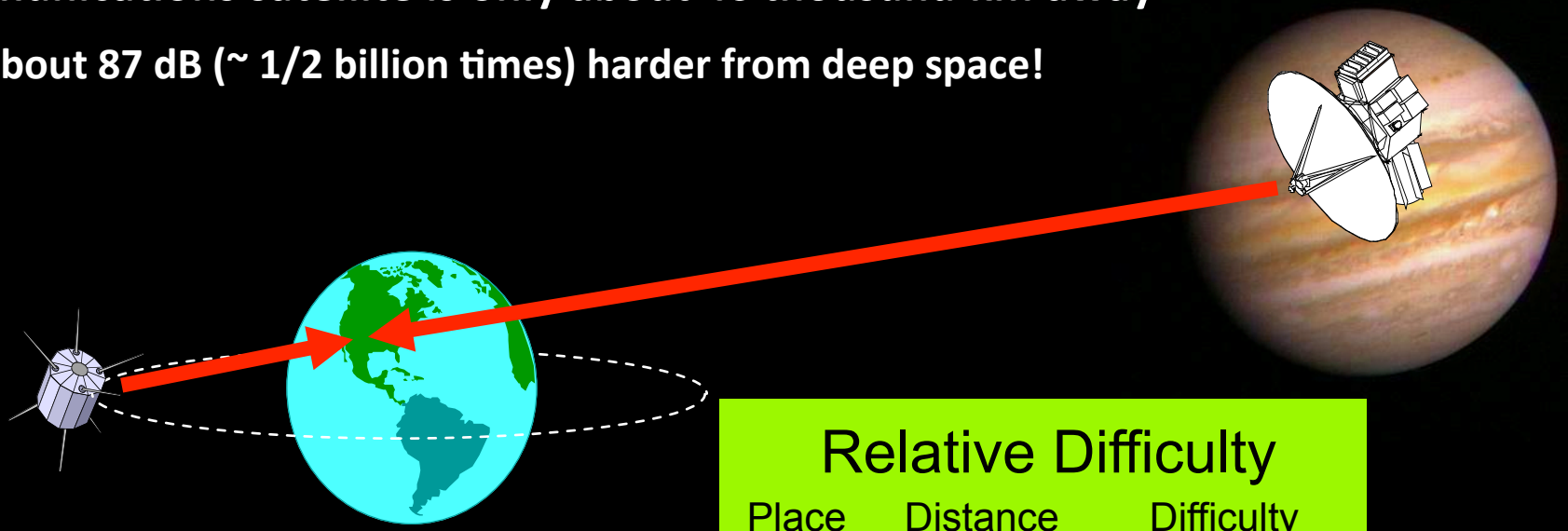
Can you hear me now?

Normalizing Communications

Communications performance decreases as the square of the distance.

Jupiter is nearly 1 *billion* km away, while a GEO Earth communications satellite is only about 40 *thousand* km away

About 87 dB (~ 1/2 billion times) harder from deep space!



Relative Difficulty

Place	Distance	Difficulty
Geo	$4x10^4$ km	Baseline
Moon	$4x10^5$ km	100
Mars	$3x10^8$ km	$5.6x10^7$
Jupiter	$8x10^8$ km	$4.0x10^8$
Pluto	$5x10^9$ km	$1.6x10^{10}$

50 Years of Science

The 20th century saw enormous strides in science & engineering

Took only 66 years to progress from first human powered flight to landing humans on the Moon

How can we begin to grasp scientific progress during lifetime of the DSN?

Council for the Advancement of Science Writing **represents science journalists who serve as bridge between scientists and public**

- **Published a "Top 50 List" – starting from 1957**
- **Pretty close to first 50 years of the DSN!**

50 Years of Science

Of top 50 science advances, the Deep Space Network was intimately involved with 22!

Not a bad record

Probably as good as any other scientific instrument

Let's examine the list and the role the DSN has played in advancing science in its first 50 years …

1. Satellites

Sputnik 1 launched in 1957, shocking the world

The DSN was built soon after, to enable much more capable satellites

Communicating with satellites was critical – as was navigating them on their journeys, particularly as they left the "safe" low Earth orbit pioneered by the Sputniks

Without the DSN, we would not have had spacecraft to the Moon and, later, to other planets

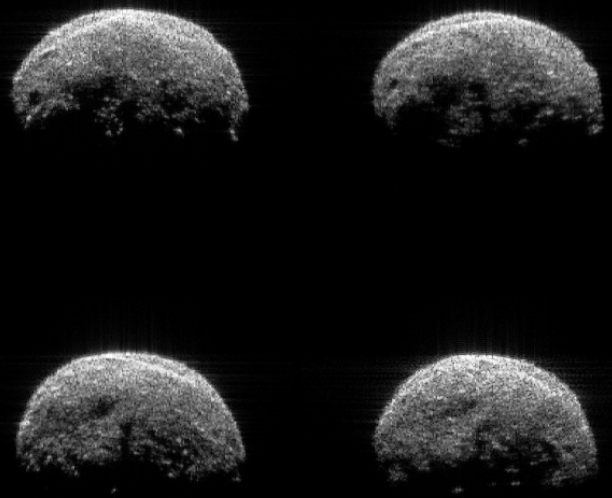
24. Killer Asteroids

Realization that a major collision by an asteroid or comet killed off the dinosaurs became accepted in 1980.

Could we be next?

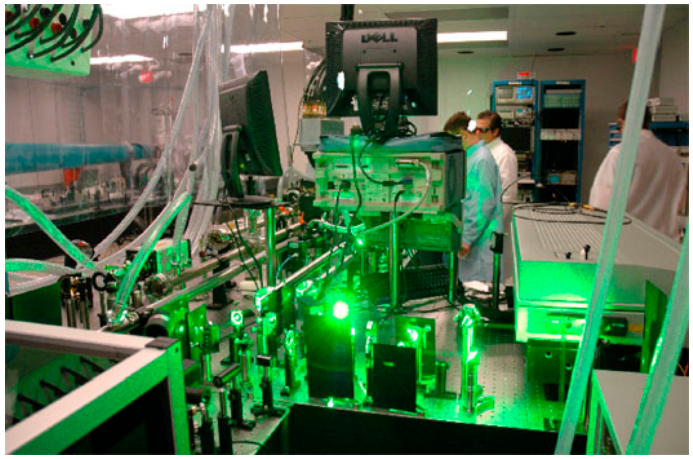
Much of what we know about asteroids and comets comes from spacecraft supported by the DSN. In addition, the science of deep space trajectories comes substantially the work of DSN researchers.

Today, DSN radar is the best tool for characterizing asteroids that might collide with Earth – calculating their size, shape, rotation, and orbit



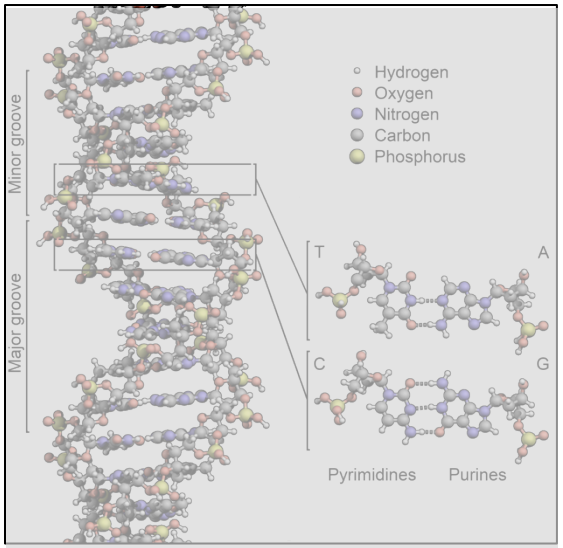
DSN-related Technology

2. 1960 – The Pill



3. 1960 – Lasers

(remember these?)



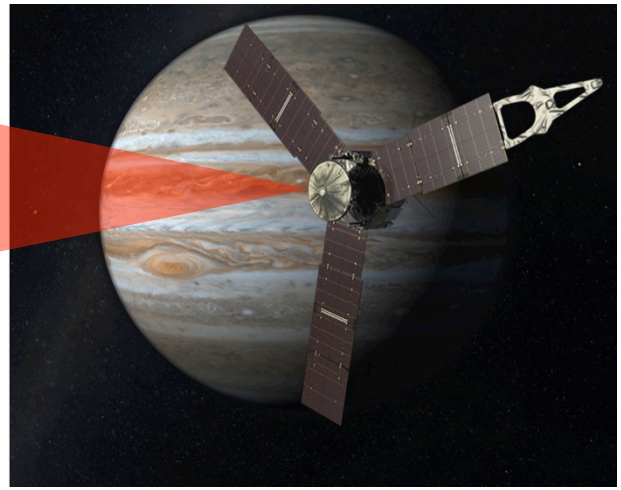
4. 1961 – DNA Code

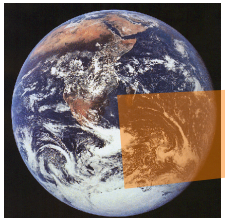
Optical Communication
Why?

Consider Juno mission at Jupiter …
(orbital insertion 2016 July 5)

0.018 Mbps
(at least)

~ 200 Earth diameters

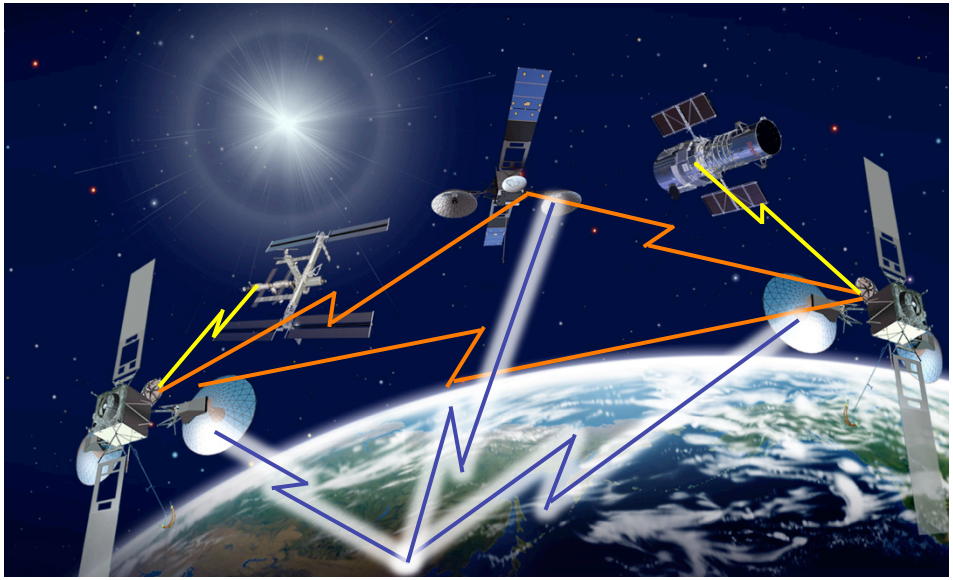




~ 2.5 Mbps (at least)

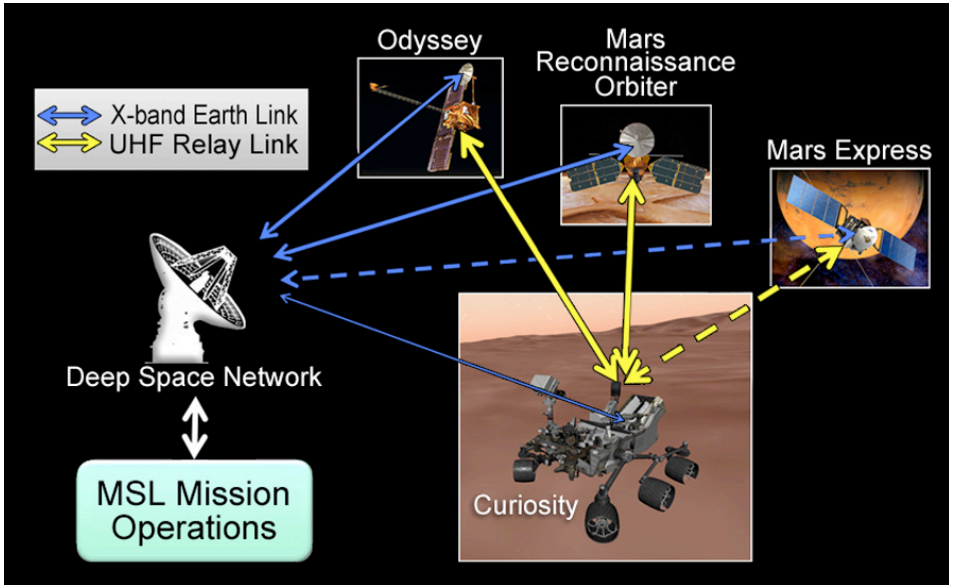
Planetary Communications Networks

Terrestrial Network



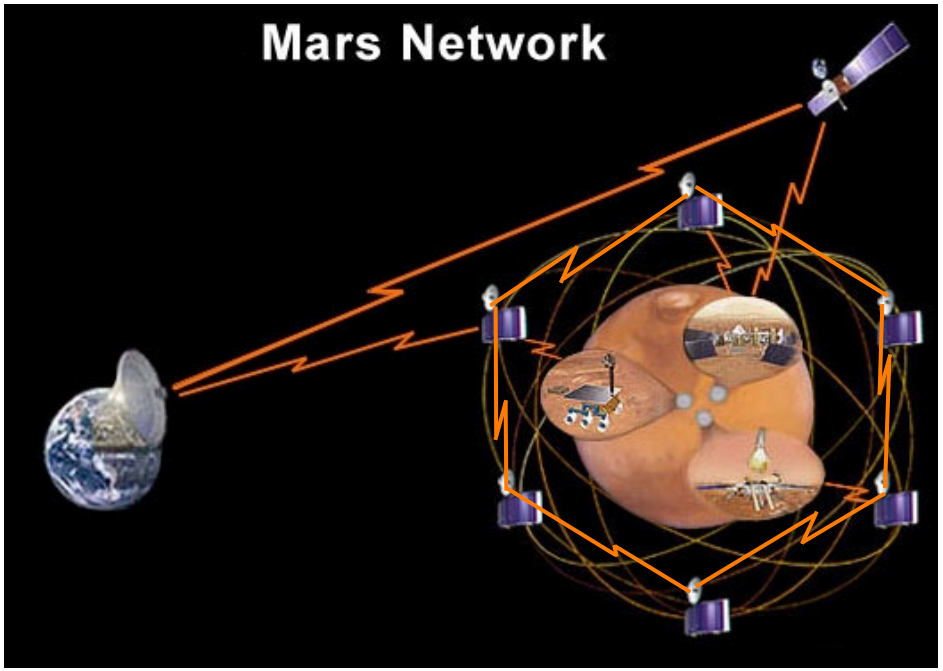
Communication flow between spacecraft, relays, and ground --- "Internet like" and robust against disruptions

Martian "Network"

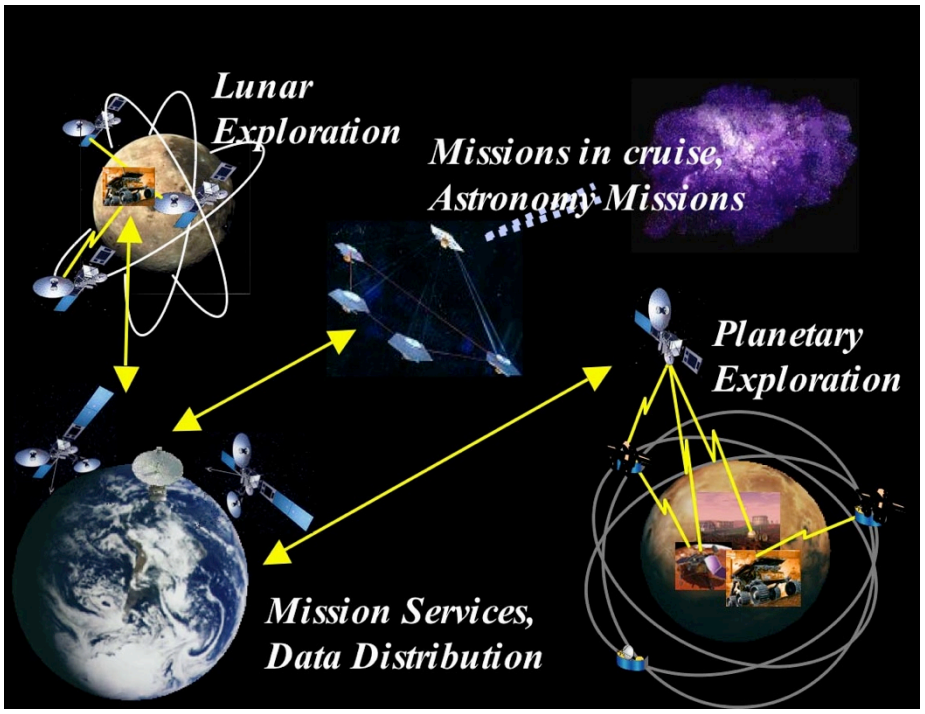


Communications between orbiters and Earth, orbiters relay communications to landers/rovers (and Curiosity can communicate directly to Earth), but …

Interplanetary Internet



Communication flow between Earth, relays, and Mars --- "Internet like" and robust against disruptions



Move into the solar system --- Moon, Mars, asteroid belt, …

Deep Space Network

50 years of enabling solar system-class (and beyond!) science

Benefits to science and society beyond simply transmitting data

Let's keep opening frontiers

Breaking Moore's Law